BRL

TECHNICAL NOTE NO. 1478
AUGUST 1962

BRL SHOCK TUBE PIEZO-ELECTRIC BLAST GAGES

Benjamin A. Granath
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Department of the Army Project No. 503-04-002
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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BAGranath/GACoulter/mec
Aberdeen Proving Ground, Md.
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ABSTRACT

This report describes in detail two small piezo-electric blast gages of one-half inch and one-quarter inch case diameters. The details of construction, testing, and use of these two gages are given. In addition, two modifications of the one-half inch gage and an experimental three-quarter inch gage are described and evaluated. Pressure time records from these gages are given.

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LIST OF FIGURES

INTRODUCTION

This report is intended to show the reader how to make, test, and use small piezo-electric blast gages of the type employed at the Shock Tube Facility of the Ballistic Research Laboratories. The information adds to and makes current the authors' previous work reported in References 1 and 2.

The gages described can be used in either laboratory or field experiments using high explosive. The one-half inch (types 1 and 3) and three-quarter inch (type 4) gages have threads for use in models or the walls of the shock tube. The smaller, one-quarter inch (type 2) diameter gage has an unthreaded case which can be used where threads are not practical. For example, it may be built into a model using the technique described in Reference 3.

All of the gages are designed to have as fast a response as possible to the applied wave. The type 4 gage was designed to have a very fast response in order to enhance its ability to measure the initial portion of the shock wave. All gages were designed with consideration given to a practical damping factor. The damping of the natural vibration determines how close the pressure-time record can be read to the actual shock front.

Photographs and drawings are given for gage types 1 and 2; exploded sketches of all types are given. The drawings along with the additional instructions, should give the reader enough information to build, test, and use the type 1 and 2 gages. Since types 3 are yet in developmental stages, the construction techniques necessarily will be omitted other than to say that the basic assembly techniques are common to all types.

Sample pressure-time shock tube records are given for each type of gage. The ringing of individual gages of a particular type may vary slightly but the records given represent what may be expected from each type.

It should be noted that the gages of types 1 through 3 contain lead metaniobate discs as the piezo-electric material and that gage 4 is of tourmaline. These choices are by no means mandatory. Any type of piezo-electric material may be incorporated into gages of the types discussed here. The choice is entirely up to the builder with consideration given to the availability, output, and stability of the material and the purpose or intended use of the gages.

GAGE ASSEMBLY

Completed gages of type 1 (the one-half inch gage) and type 2 (the one-quarter inch gage) are shown in Figure 1 along with a matching 36-inch cable (Microdot No. 50-3804 cable with two 32-21 end plugs).

Figures 2 and 3 are the machine drawings necessary to construct the components of the type 1 and 2 gages. A reasonably skilled machinist with the usual shop tools, should be able to furnish the components as specified on the drawings.

An exploded assembly drawing of the type 1 gage is shown in Figure 4. The piezo-electric material (in the type 1 gage a lead metaniobate disc 3/16" diameter 0.050" thick), part 3, is cemented to the nylon insert, part 4, which has previously been press fitted into the steel case, part 6. A small spring, part 5, provides the electrical contact between the disc and the center conductor of the co-axial connector (Microdot 31-02), part 7. The spring must pass through the insert, part 4, and fit over the end of the co-axial connector, part 7, and provide enough compression to maintain the electrical contact between the disc and connector. The nylon cap, part 1, is then pressed and cemented into the case in contact with the disc. All cementing should be done with Eastman 910 adhesive. In all cases the adhesive should be used sparingly and in the case of the disc, no adhesive should be directly applied. In order to cement the disc, the adhesive should be placed only on the nylon pieces on either side of the disc. The dimensions are so arranged that the cap of the fully assembled gage will protrude slightly beyond the face of the gage case. The face of the gage should be lapped smooth using a fine emery cloth or polishing paper. The completed gage is now ready for testing.

The methods described above are also used in assembling gages of types 2 through 4, the primary differences being modifications in the actual gage components.

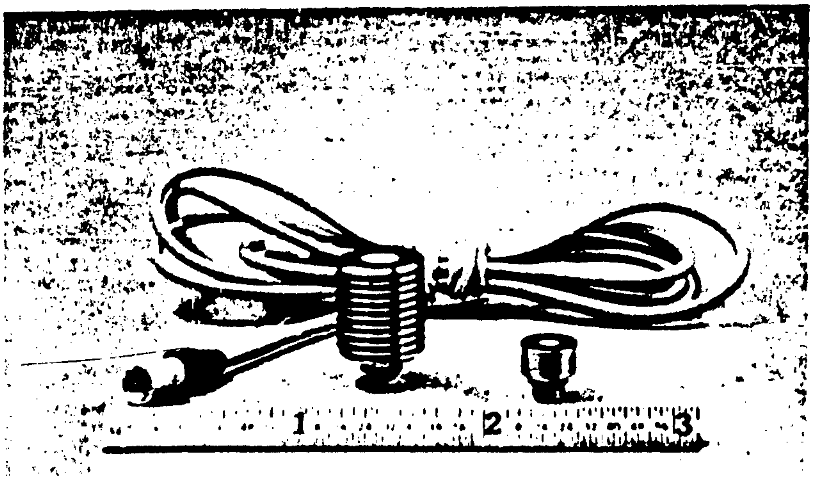


Fig. 1 Photograph of the Gages - Types 1 and 2

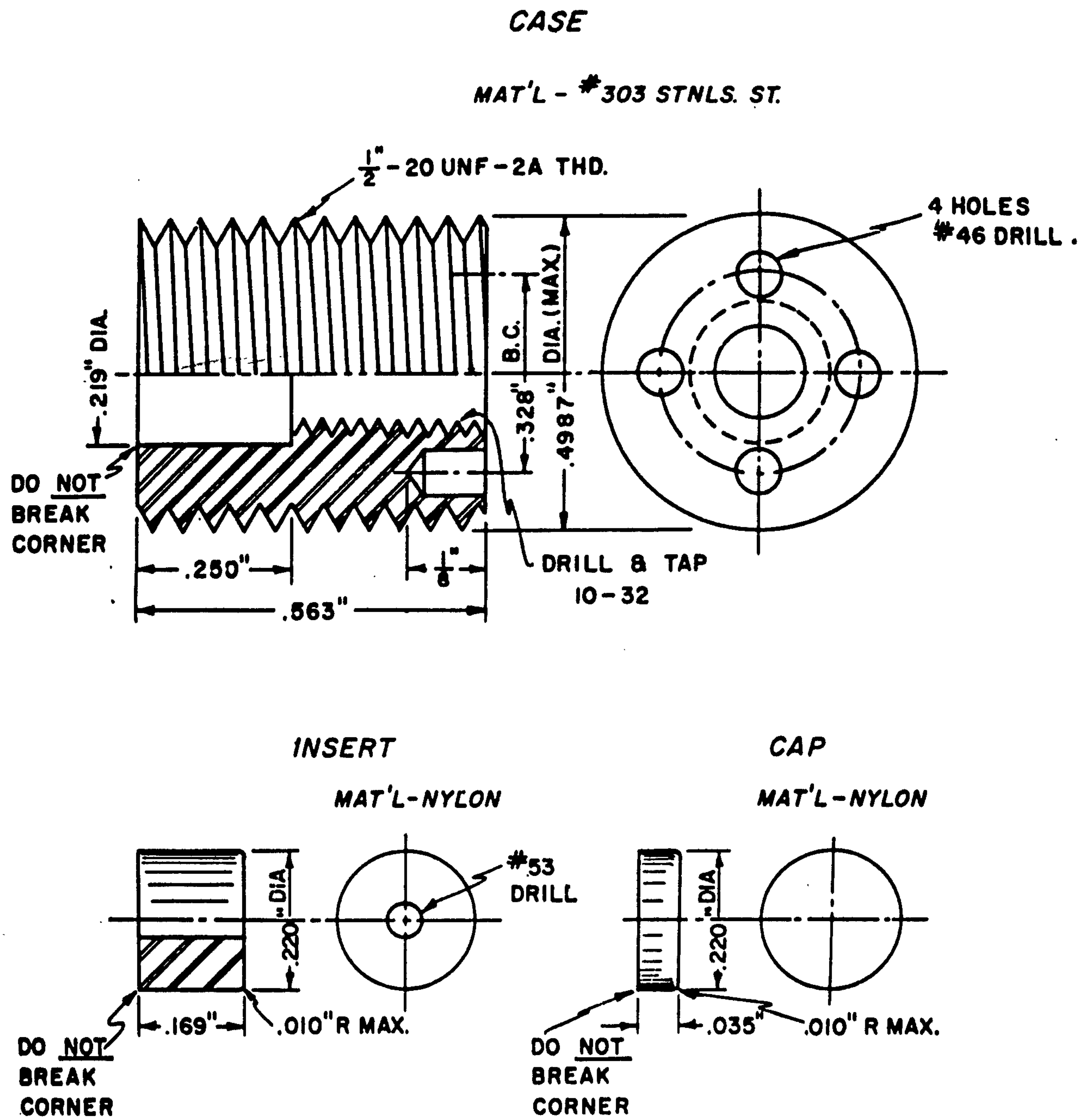


FIG. 2 DRAWING FOR THE HALF-INCH GAGE

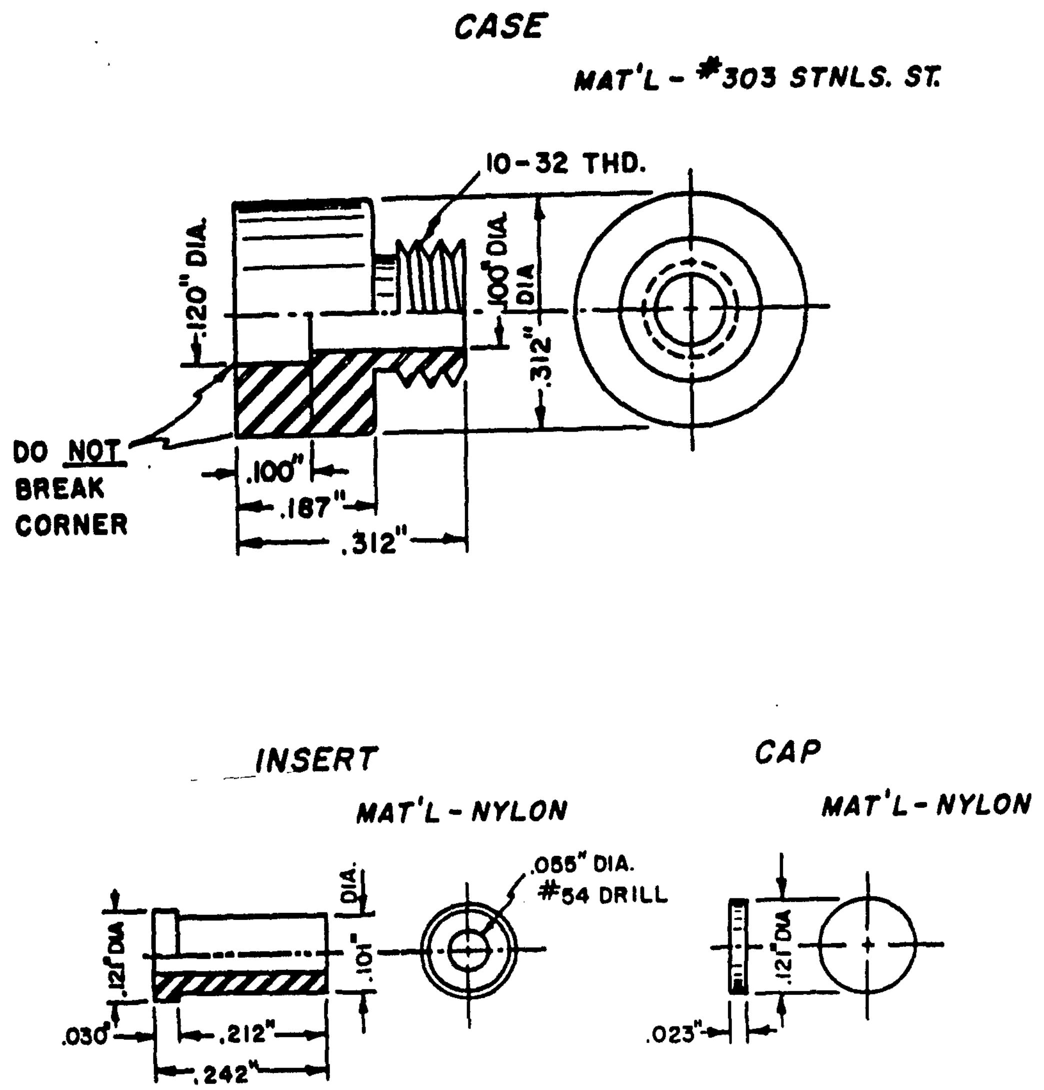
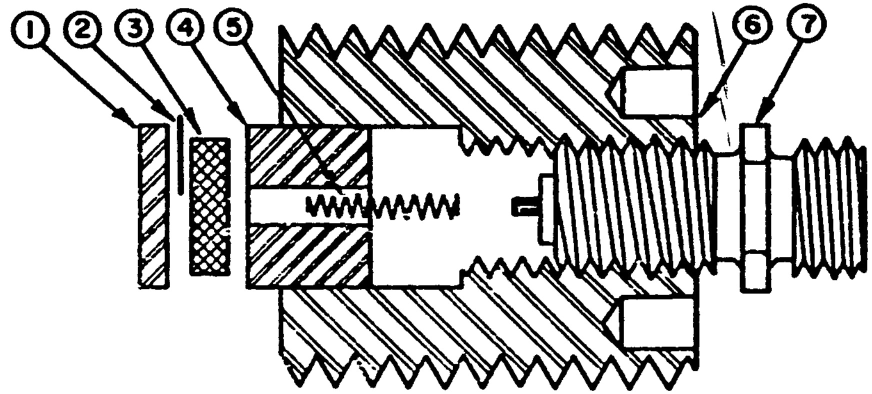


FIG. 3 DRAWING FOR THE QUARTER-INCH GAGE



1 NYLON CAP
2 METAL FOIL GROUNDING TAB
3 CERAMIC PIEZO-ELECTRIC ELEMENT
4 NYLON INSERT
5 CONTACT SPRING
6 STAINLESS STEEL GAGE CASE
7 CO-AXIAL CONNECTOR

FIG. 4 EXPLODED VIEW OF HALF-INCH GAGE

RECORDING SYSTEMS

The output from piezo-electric gages is normally recorded on oscillographic type recording systems. Two such systems are described here. Figure 5 shows them in block diagram.

System A, the simpler of the two, consists of a blast gage, a suitable cathode follower (Figure 6) to couple the high impedance blast gage to the relatively low impedance amplifier, and an oscilloscope equipped with a recording camera. References 4 and 5 have more complete descriptions of components of this type of system.

System B, also shown in Figure 5, has the advantage of being capable of recording the records from several gages simultaneously. Moving film cameras are used for this purpose. Film speeds up to 100 ft/sec have been used successfully to record short duration blast waves while slower recording speeds (10 ft/sec) have been more useful for recording blast waves of long duration. Reference 6 describes such a system.

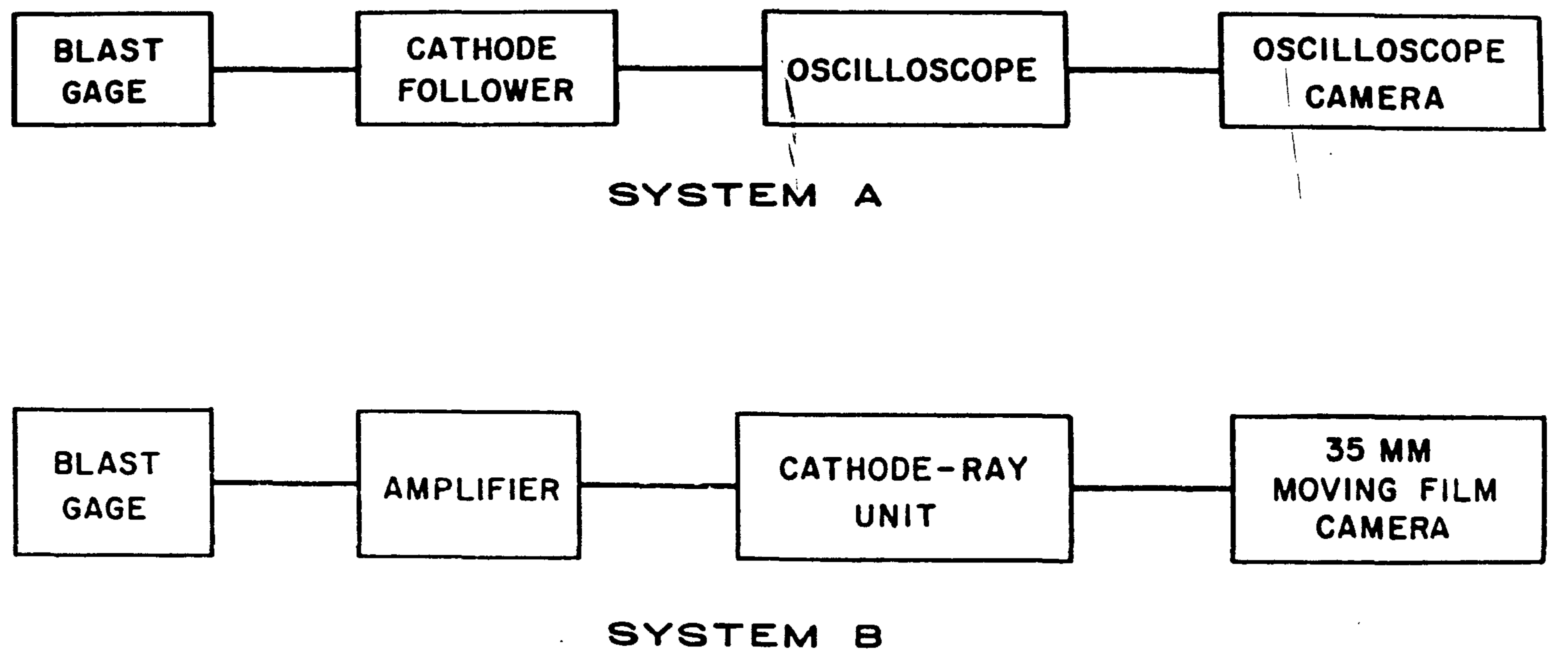
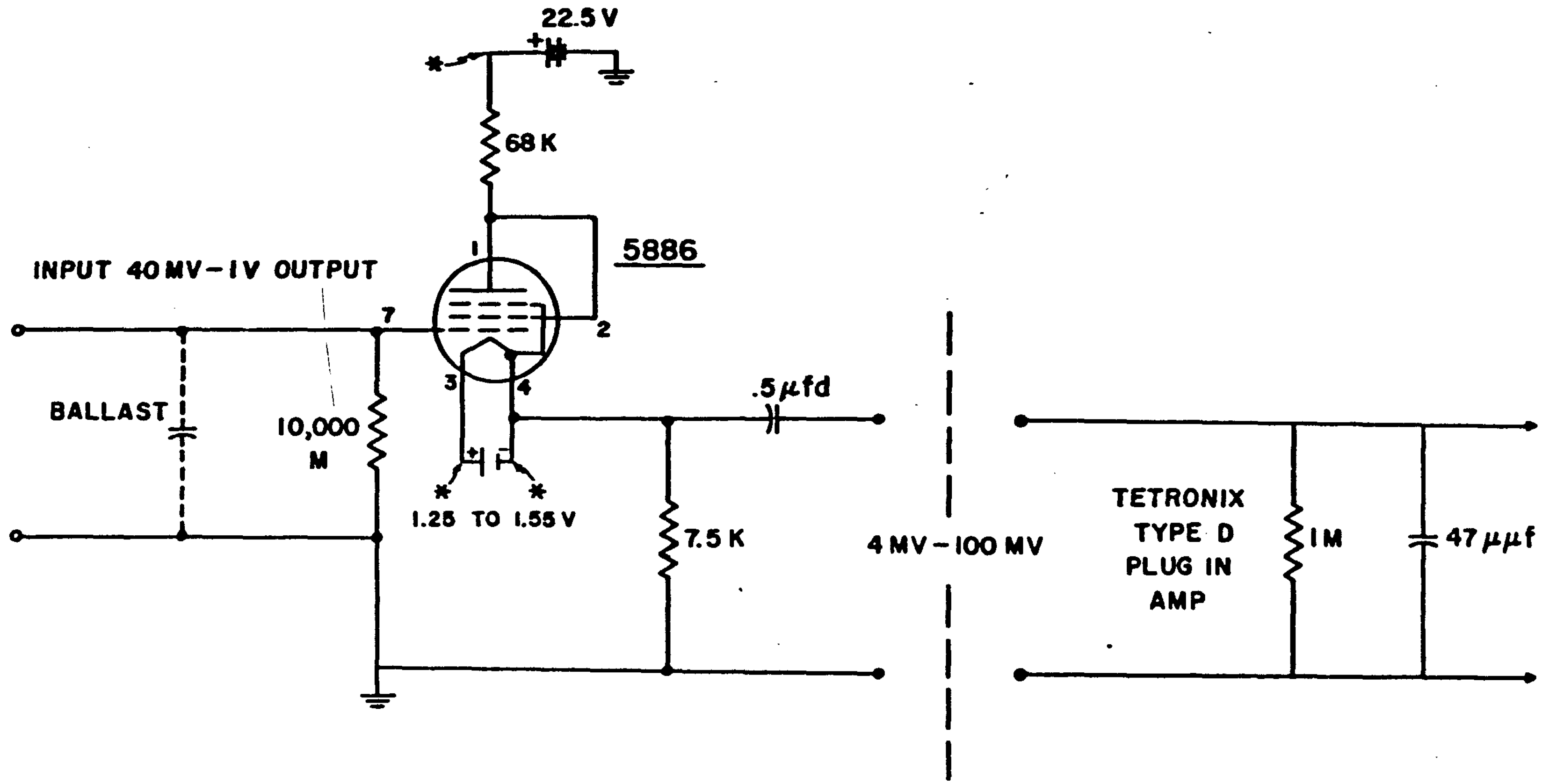


FIG. 5 BLOCK DIAGRAM OF THE RECORDING SYSTEMS



* TEST JACK; RISE TIME LESS THAN 3 μ SEC.
AVERAGE LEAD-METANIOBATE GAGE PUTS 40 MV/PSI ACROSS 500 μμf

FIG. 6 CATHODE FOLLOWER CIRCUIT

CALIBRATION

Calibration of the complete system (recorder, cables, and gage) is made in the following way. An assumption of the overpressure of the wave to be measured is made. A somewhat larger pressure (25 percent greater) is applied to the gage by the pulse calibrator. The gain of the recording amplifier is adjusted to give full usable deflection on the oscilloscope for the applied pressure pulse. The pressure pulse is recorded with the camera. The system is now calibrated.

After calibration the gage is placed in the experimental position. Care should be taken to insure that the cables and connectors used in the recording are the same as used in the calibration and that the resistance of the cables to ground be at least 50,000 megohms. To keep all errors caused by a change in gain of the system to a minimum, calibrations should be made just before and just after the experimental wave is recorded. If available, a known voltage step may be recorded along with both the calibrations and the experimental record to indicate any change in amplifier gain that might have occurred.

GAGE EVALUATION

Either of the two recording systems may be used to test the gages. Gages at BRL are usually tested using the oscilloscope equipped with a Polaroid Camera to furnish quick results. After a recording system is chosen, three separate tests are made on the completed gage. One test is made with a pulse calibrator (one type of calibrator is described in Figures 7 and 8) and the other two tests are made with the shock tube, Figure 9. Figures 10 and 11 show test records from both Systems A and B. The three tests are:

1. Pressure pulses of different magnitudes are applied to the gage while maintaining a constant gain setting on the recording system. The output of the gage should be linear with respect to the calibration pressure pulses. The outputs should be approximately 50 millivolt/psi for gages of types 1 and 3; about 10 millivolt/psi for the type 2 gage, and 2 millivolt/psi for the type 4 gage. These outputs are obtained with 3 feet of cable (Microdot No. 50-3804) at an input of 1 megohm and 47 μμf (Tektronix 541-Type 53/54D Amplifier) without a cathode follower. Another criterion for acceptance of a gage under this test is that the gage output be high enough to be useful at the intended pressure range. Sample calibrations from gages of types 1 and 2 are shown in Figure 11-A. The lower trace is from type 1; upper trace is from type 2.

2. The gage is then placed in the side wall of the shock tube and a low pressure shock wave (shock overpressure of 10 psi) is passed over the gage. Figure 11-B shows records from this type of a test. This record should be examined for two separate phenomena. First, the value of the shock pressure, obtained from the pulse calibration should agree within 1 percent with that pressure calculated from a velocity system measurement (References 2, 7, 8, and 9). Secondly, the pressure-time record should be examined for gage vibration or ringing. Slight variation should be expected in the record due to the non-ideal shock produced by the shock tube.

3. The final test is made to determine the frequency, magnitude, and duration of the vibration or ringing of the gage. In order to accomplish this the gage should be mounted flush in the end plate of the shock tube and subjected to a shock wave. See Reference 10 for a complete description of this method. The ringing should stop as near the beginning of the pressure-time record as possible (Figures 10 and 11-C).

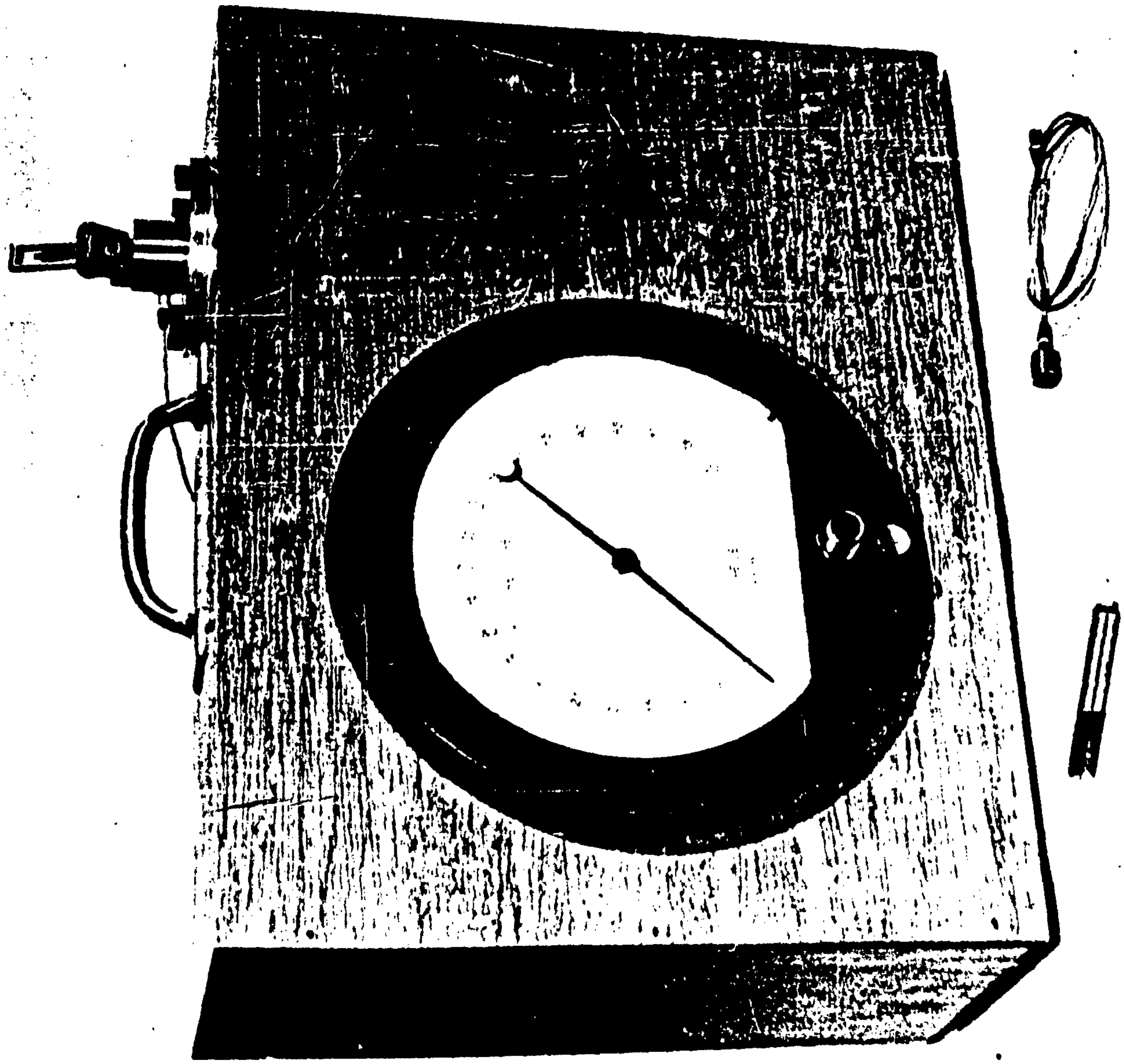
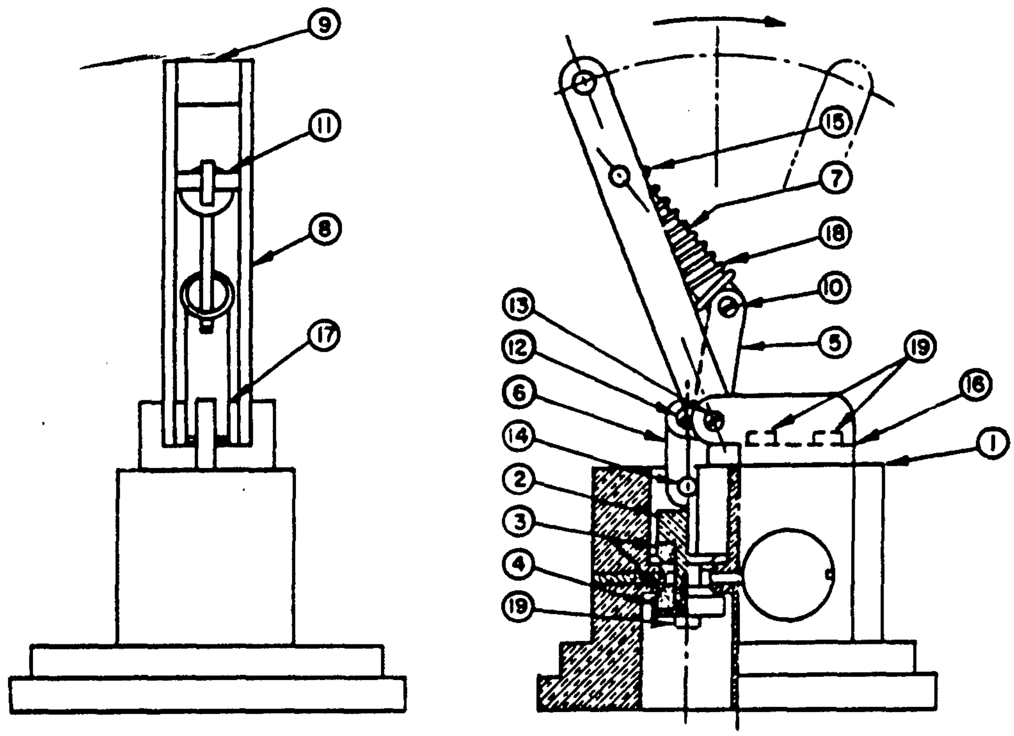


Fig. 7 Photograph of the Calibrator

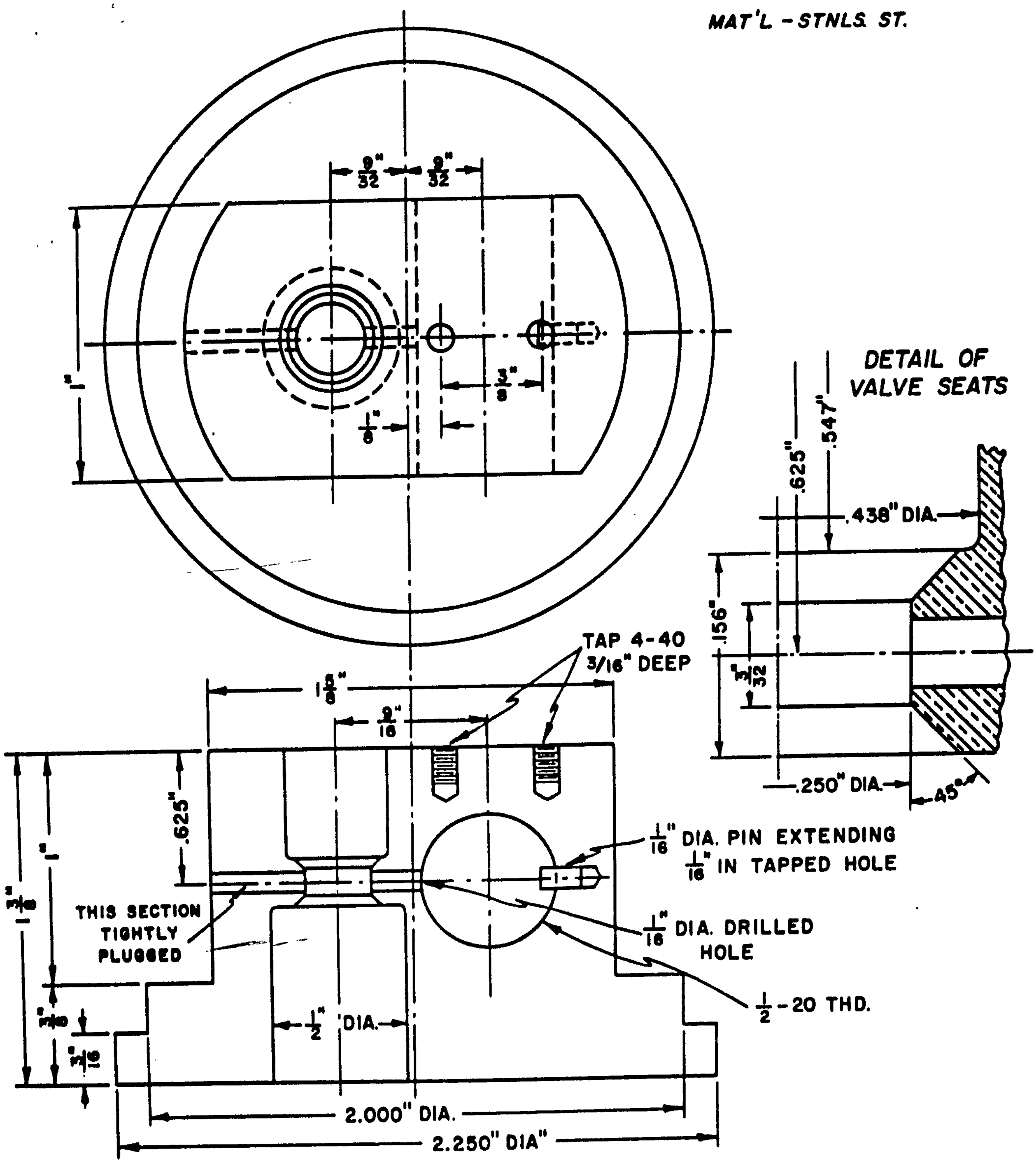
SNAP-ACTION CALIBRATION VALVE
FOR
PIEZO-ELECTRIC GAGES



PART NO.	QUAN.	DESCRIPTION	PART NO.	QUAN.	DESCRIPTION
1	1	VALVE BODY	11	1	SHAFT
2	1	PLUNGER	12	1	"
3	2	VALVE FACE	13	1	"
4	1	LOWER CUP	14	1	"
5	1	ROCKER	15	2	SPG. GDE. WASH
6	1	CON. LINK	16	1	LEVER BASE
7	1	SPG. GUIDE	17	2	WASHER
8	2	LEVER SIDE	18	1	SPG. $\frac{3}{16}$ I.D x 1" LG.
9	1	HANDLE	19	3	4-40 x $\frac{1}{4}$ SK. HD. SCW
10	1	SHAFT			

FIG. 8 DRAWINGS FOR THE CALIBRATOR

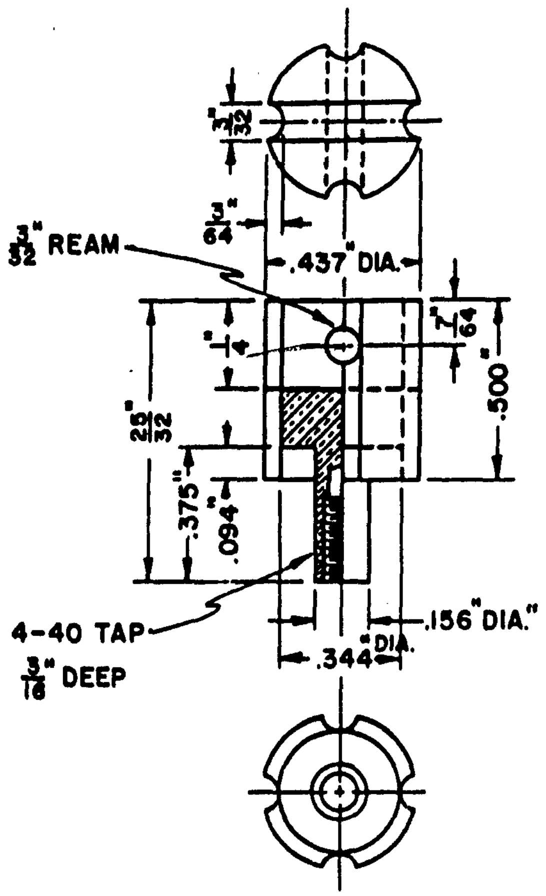
VALVE BODY



PART #1

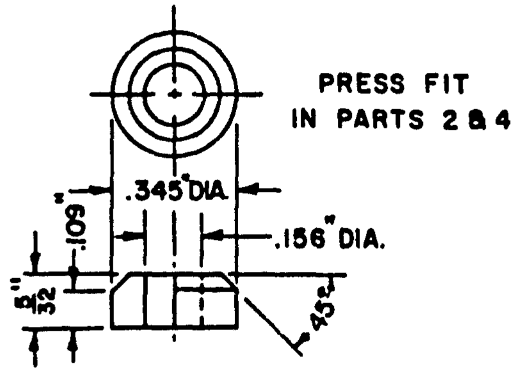
FIG. 8 CONTINUED - PAGE 2 OF 4

PLUNGER
MAT'L - STNLS. ST.



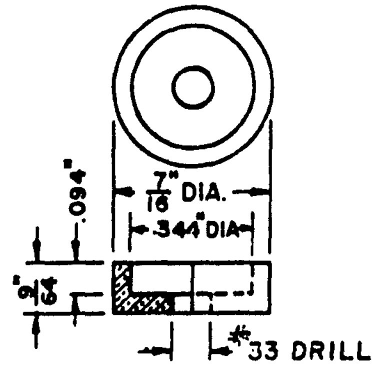
PART #2

VALVE FACE
MAT'L NYLON
2 REQ'D



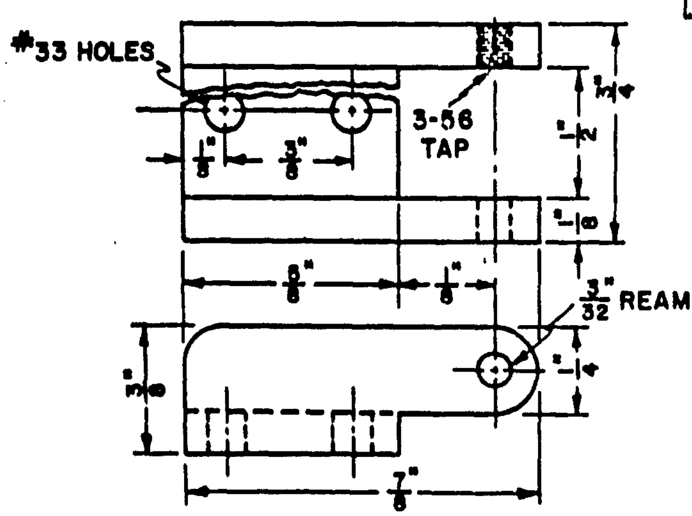
PART #3

LOWER CUP
MAT'L - STNLS ST.



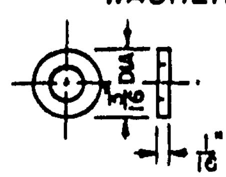
PART #4

LEVER BASE
MAT'L - STNLS. ST.



PART #16

WASHER
MAT'L - BRASS
2 REQ'D



PART #17

FIG. 8 CONTINUED - PAGE 3 OF 4

SNAP ACTION LEVER PARTS
MAT'L - STNLS. ST.

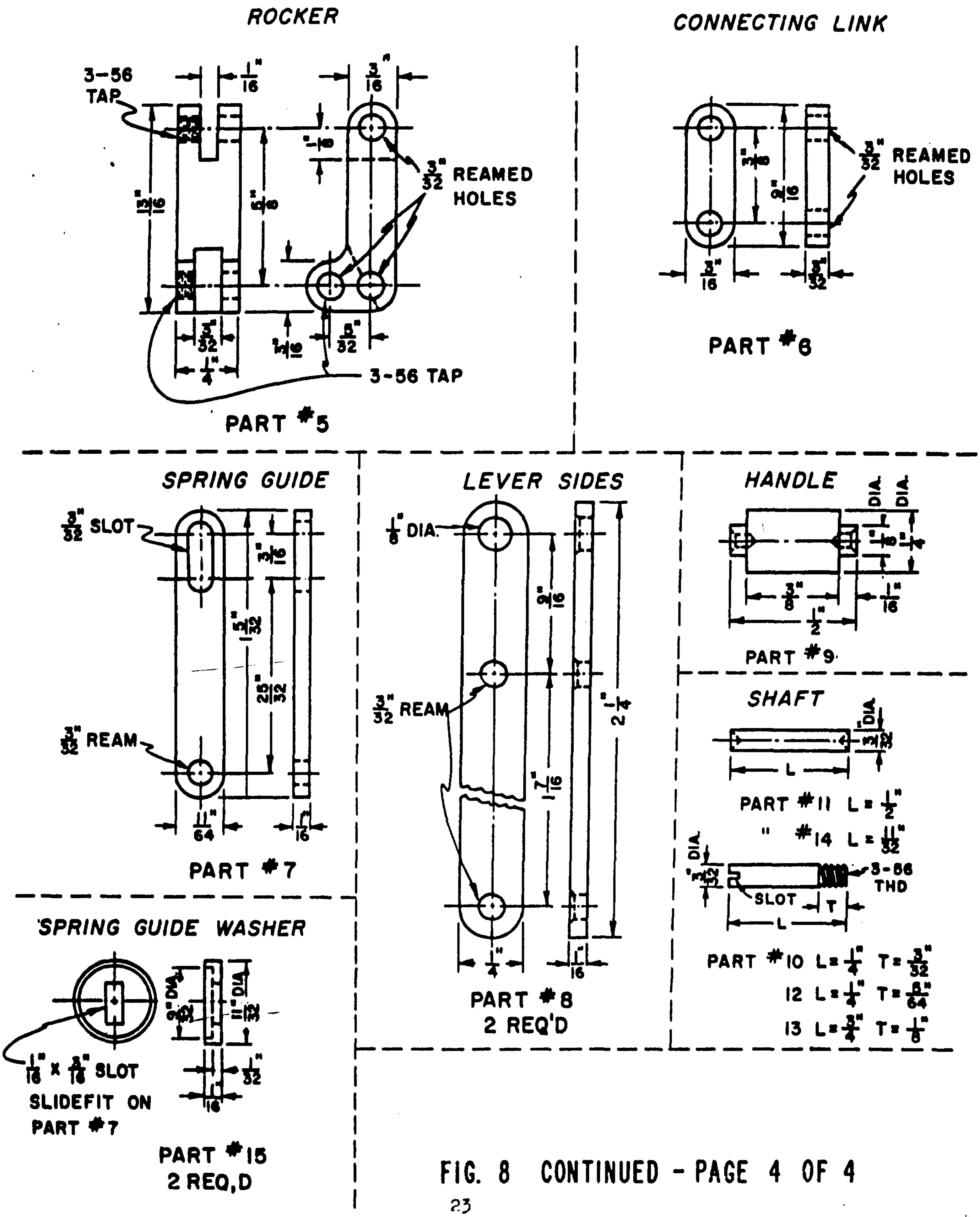


FIG. 8 CONTINUED - PAGE 4 OF 4

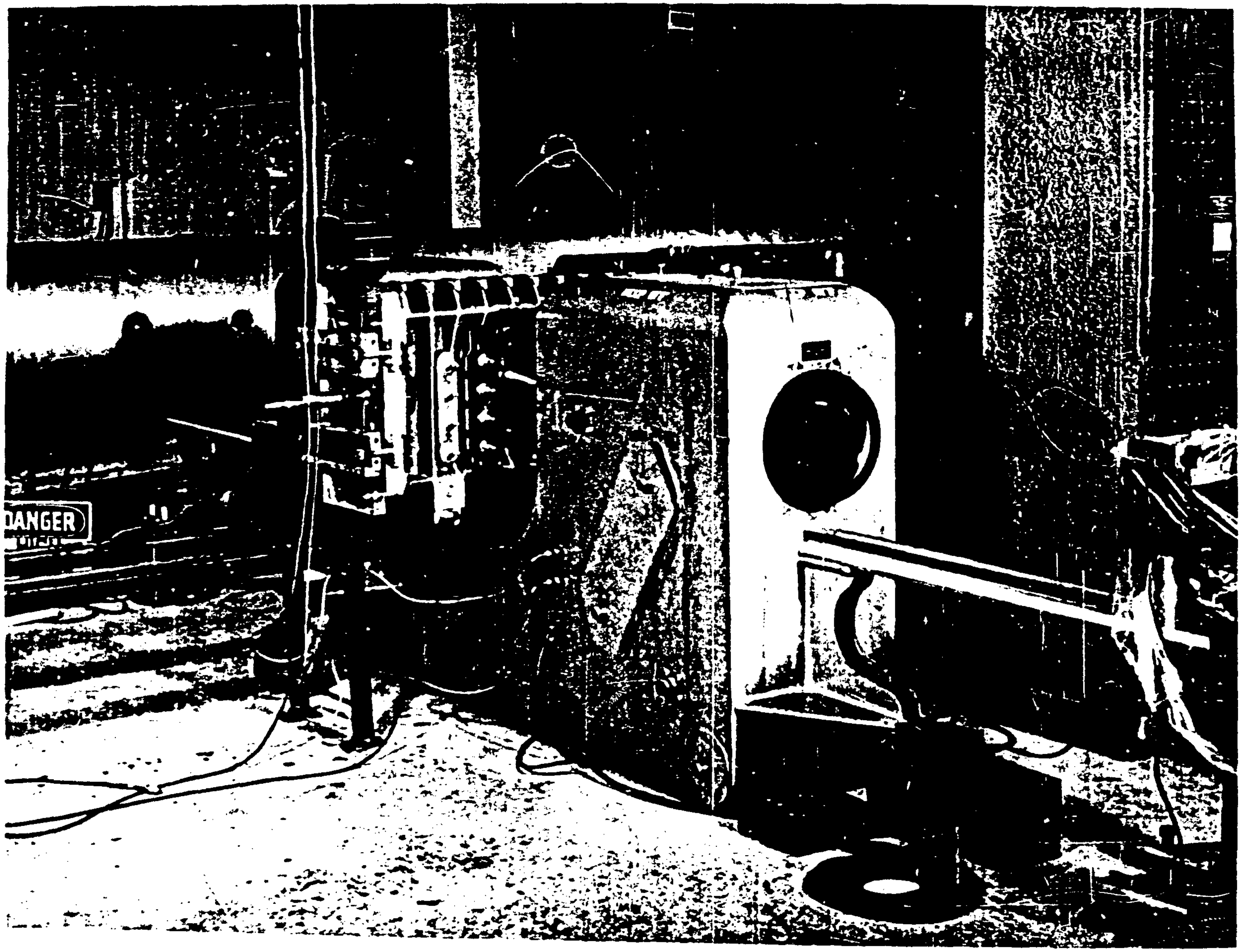
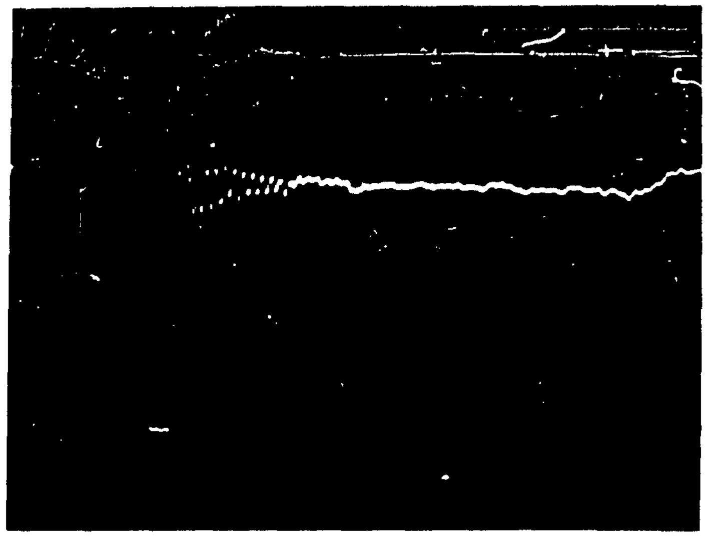
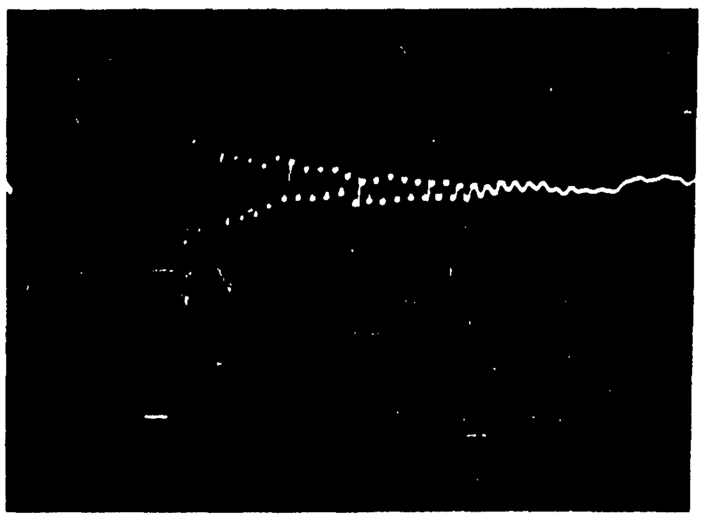


Fig. 9 4x15 Inch Shock Tube

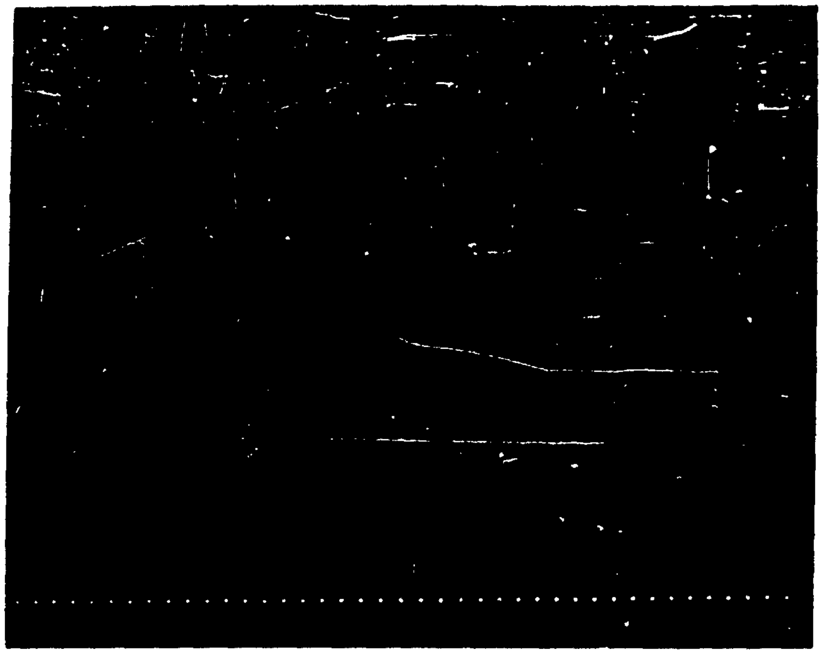


Time, 50μsec/cm
Figure 10A Quarter-Inch Gage-End of Shock Tube

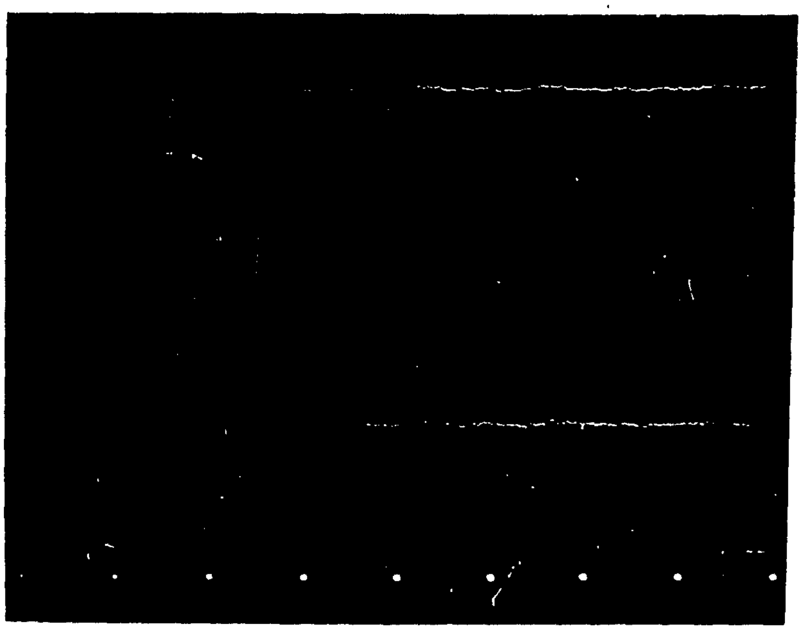


Time, 50μsec/cm
Figure 10B Half-Inch Gage-End of Shock Tube

Figure 10 Pressure-Time Records-System A



Time, msec
Figure 11A Static Calibrator Records



Time, msec
Figure 11B Shock Tube Records-Side Wall

Figure 11 Pressure-Time Records-System B

Pressure

Time, msec

Figure 11C Shock Tube Records-End of Shock Tube

Figure 11 (continued) Pressure-Time Records-System B

COMPARISON OF THE GAGES

Table I is a tabulation of the characteristics of the four types of gages considered in this report. Included in this table are the dimensions, output, frequency, duration, and magnitude of ringing, and piezo-electric material for each type of gage. Figures 12, 13, 14, and 15 show exploded views, lists of parts, and typical records obtained from the four gage types. All of the records were taken under identical conditions. The gages were mounted in the end of the shock tube and subjected to identical shock waves. Only the amplifier gain was varied to make all record heights approximately the same. The sweep speed of the oscilloscope was 20 μsec/cm in all cases.

Some general statements can be made concerning the characteristics and use of each of the types of gages.

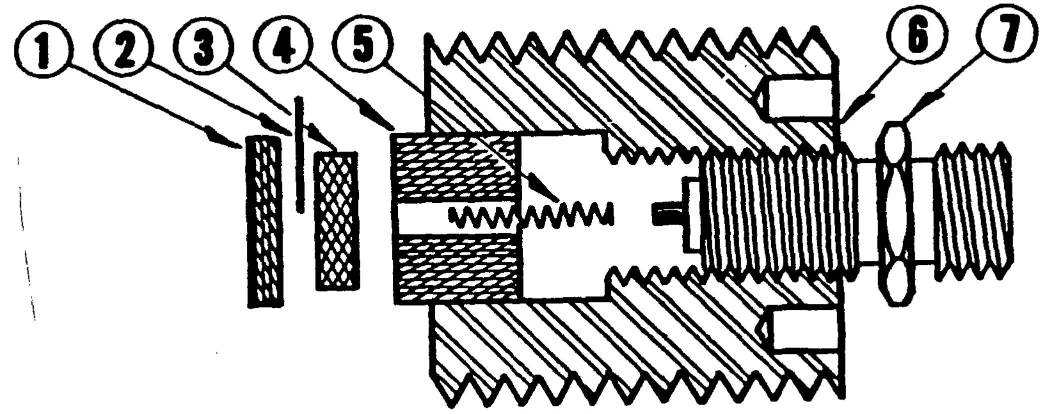
Type 1 --- This gage has the lowest frequency and the longest duration of ringing. It has the advantage of having a high output and can be used successfully in side-on applications particularily at pressures in the range of 0.2 to 30 psi.

Type 2 --- This is the smallest gage and can be used more conveniently in small models and where threads are impractical.

Type 3 --- This gage differs from type 1 only in its frequency and duration of ringing.

Type 4 --- This is the largest of the four gages. It will be noted that this gage exhibits only one cycle of ringing and that the magnitude of this ring is very small. This gage is useful in face-on applications where the shock overpressure is in excess of 10 psi.

It might be mentioned at this time that a gage with the least magnitude or duration of ringing, or the fastest rise time is not always the best choice for a particular application. For instance, a gage of type 1 is much more useful for recording where the record is to be examined at times late in the phenomena than a type 4 gage even though the type 1 gage has a longer rise time and rings at 100 KC for 150 μsec. Also due to variations in the individual piezo-electric elements and the packaging, individual gages will exhibit slightly varying rise



1 NYLON CAP
2 METAL FOIL GROUNDING TAB
3 CERAMIC PIEZO-ELECTRIC ELEMENT
4 NYLON INSERT
5 CONTACT SPRING
6 STAINLESS STEEL GAGE CASE
7 CO-AXIAL CONNECTOR

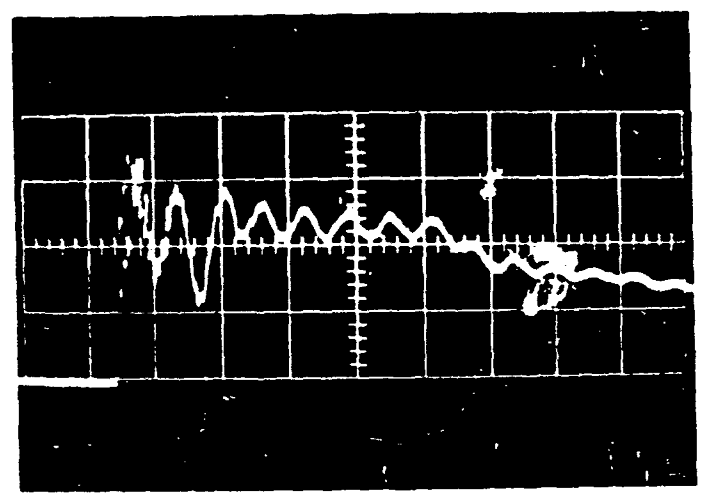
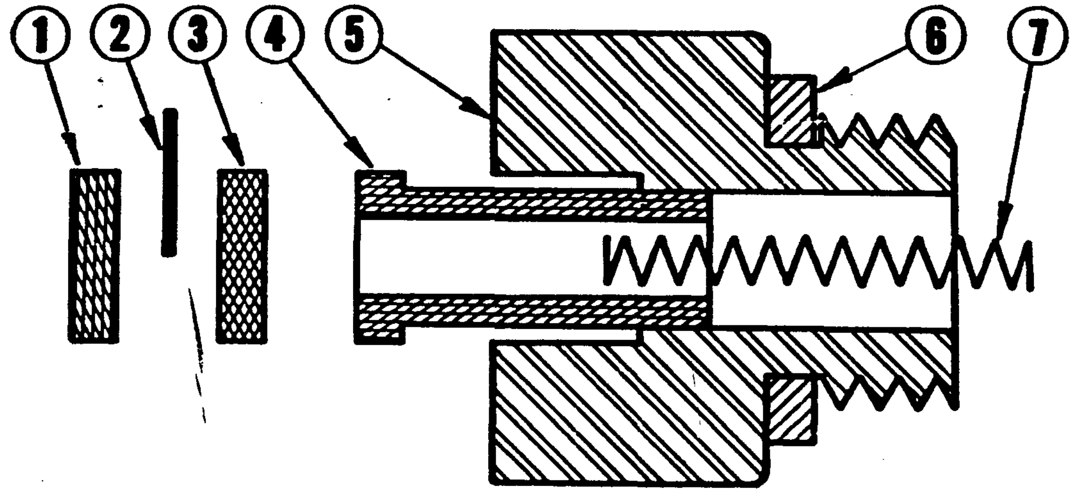


FIG. 12 TYPE I GAGE



1 NYLON CAP
2 METAL FOIL GROUNDING TAB
3 CERAMIC PIEZO-ELECTRIC ELEMENT
4 NYLON INSERT
5 STAINLESS STEEL GAGE CASE
6 RUBBER WASHER
7 CONTACT SPRING

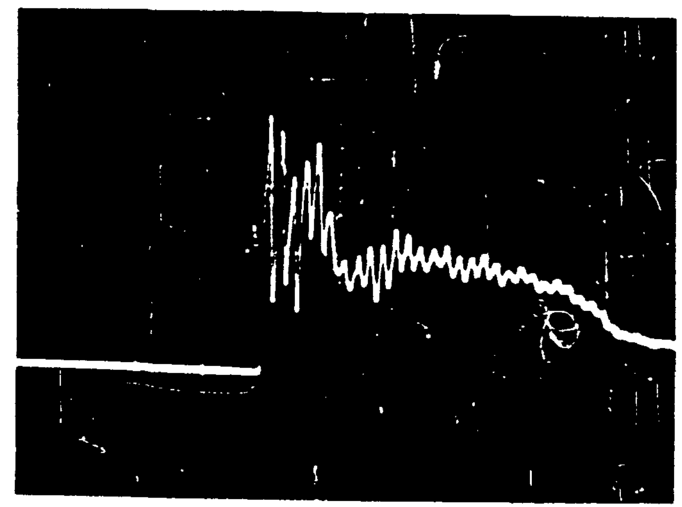
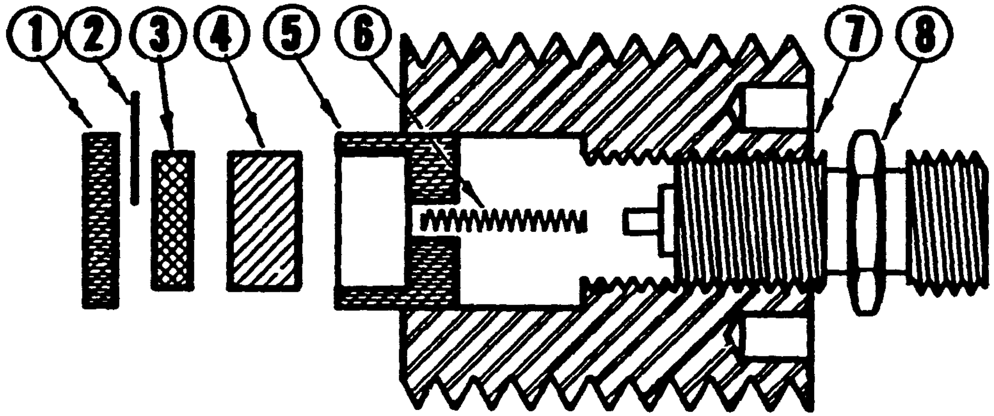


FIG. 13 TYPE 2 GAGE



1 NYLON CAP
2 METAL FOIL GROUNDING TAB
3 CERAMIC PIEZO-ELECTRIC ELEMENT
4 DISC
5 NYLON INSERT
6 CONTACT SPRING
7 STAINLESS STEEL GAGE CASE
8 CO-AXIAL CONNECTOR

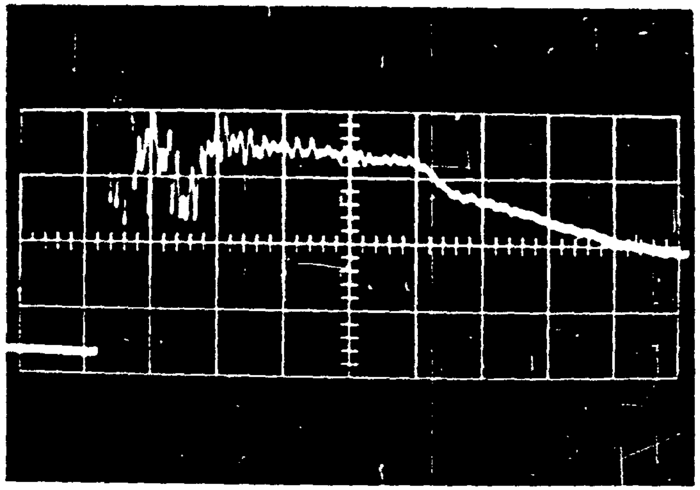
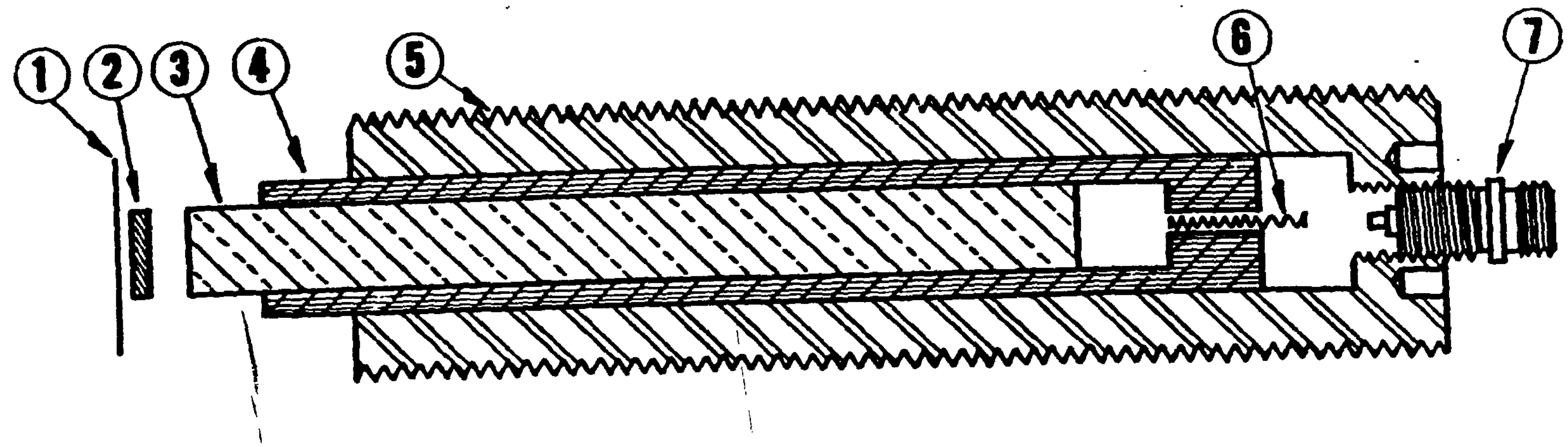


FIG. 14 TYPE 3 GAGE



1 METAL GROUNDING WIRE
2 PIEZO - ELECTRIC ELEMENT
3 BRASS ACOUSTIC WAVE GUIDE
4 NYLON OR TEFLON INSERT
5 STAINLESS STEEL GAGE CASE
6 CONTACT SPRING
7 CO - AXIAL CONNECTOR

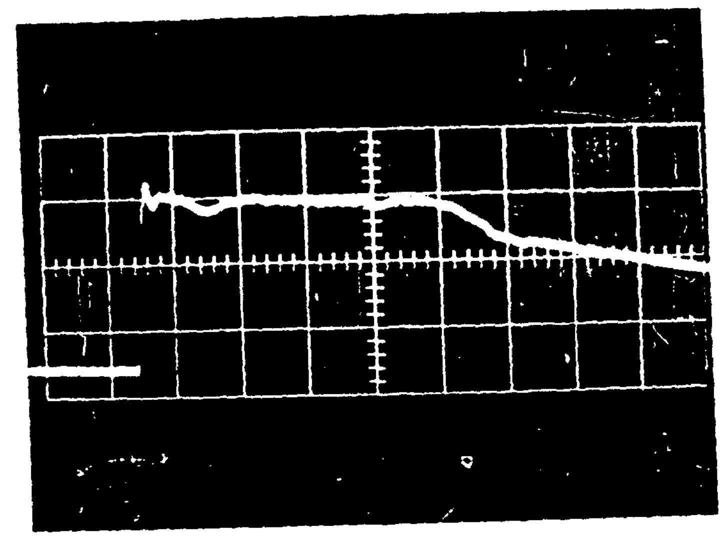


FIG. 15 TYPE 4 GAGE

times, ringing characteristics and long duration reliability. For this reason, not only should the type of gage be considered in the selection but also gages within a particular type should be examined.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the help of Mr. Rodney Abrahams who designed and built the cathode follower described in this report and to Mr. Charles Hoover who designed the calibrator head used on the pulse calibrator.

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Table I. Characteristics of the BRL Shock Tube Piezo-Electric Blast Gages

TYPE	DIMENSIONS DIAMETER (inches)	LENGTH (inches)	THREAD (ASME)	PIEZO-ELECTRIC MATERIAL	NATURAL FREQUENCY (KC)	VIBRATION MAGNITUDE (% of record)	(RINGING) DURATION (μsec)	OUTPUT (mvolt/psi)
1	1/2	3/4	1/2-20	Lead Metaniobate	100	± 30	150	50
2	1/4	5/16	---	Lead Metaniobate	140	± 30	100	10
3	1/2	3/4	1/2-20	Lead Metaniobate	250	± 30	50	50
4	3/4	3 1/4	3/4-16	Tourmaline	---	---	---	2

SUGGESTIONS TO ASSURE ACCURACY

A list of suggestions is given below to help the experimenter make his measurement accurate as possible.

1. Choose the blast gage with rise time and ringing characteristics suited to the assumed type and duration of the unknown blast wave.

2. Choose the camera or sweep speed needed to record the assumed duration of the blast wave.

3. The pressure standard for the pulse calibrator must be accurate; use a dead weight tester if possible.

4. Calibrate the gages before and after use and as near to the time of use as possible.

5. Make calibration records near the height of the assumed blast wave.

6. Read the records after the initial gage ringing has stopped. An accuracy within $\pm$ 2% can be expected if the above suggestion are followed.

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